Federal Managers Update on the National Ignition Campaign (NIC)

February 14, 2012

On January 31, 2012, Federal Managers consisting of Jeff Quintenz (Leader), Dave Crandall, Kirk Levedahl, John Sethian, Sean Finnegan (SC) and Sam Brinker (LSO) were briefed by the National Ignition Campaign (NIC) team at Lawrence Livermore National Laboratory (LLNL) in an intensive, full day session (agenda attached). There were a number of observers invited by LLNL and the observers were included in some discussions of technical points. At the end of the day, Federal Managers only met to discuss progress and issues. Thereafter, the NIC team was briefed by the Federal staff. This report is a summary of the status of the NIC by the Federal staff.

While the gaps in understanding and the output of experiments (neutron yield times target areal density at about 10% of expected value for ignition) have not changed appreciably since the 4th Koonin review of October 28, there has been notable progress. The engagement of a broader set of scientists at LLNL and the inclusion of new physics insights are addressing some of the gaps in understanding identified in the October Koonin review. The experimental and diagnostics teams have made noteworthy improvements in the quality of the data that are being obtained and in the techniques used to extract relevant information about target performance from those data. The increased shot rate in January was significant. Overall, there has been an increase in the sophistication and quality of experiments, a shortening of the time between experiments, and better quantitative comparisons of model predictions with experimental data. These improvements are a continuation of the advances noted in the report of the 4^{th} Koonin review. The recent improvements in diagnostic capability and shot rate will need to be sustained to complete the planned work of the NIC before its conclusion at the end of FY12; with these sustained, the planned program of work can be executed in this time frame.

Experimental Improvements

Since the 4^{th} Koonin review, experimental progress included:

- Completed a campaign of 24 cryogenic shots to control the shape of the capsule implosion by tailoring the laser energy distribution and managing cross-beam energy transport.
- Conducted a “pressure” campaign of 13 cryogenic shots to increase implosion velocity and capsule compression by increasing the power and modifying the timing (and the rise) of the 4^{th} power step of the laser. Two experiments using gold-coated uranium hohlraums rather than gold hohlraums have demonstrated the increased radiation efficiency of these new hohlraums, although routine use of uranium hohlraums has been deferred until experiments that will be conducted after February 2012. Improved measurements of in-flight properties (velocity and thickness) of the capsule ablator and of neutron and x-ray images of the compressed reacting core, provide data consistent with the interpretation that these properties are associated with low areal density and pressure in the compressed core.
- As an example of improved experimental technique, registration of x-ray images, fusion neutron images, and down-scattered neutron images, demonstrate spatial asymmetries in

colder compressed material. The images extracted from this technique may be indicative of jetting from the fill tube distorting the compressed core more than predicted by modeling.

- Developed an improved method for estimating the size of the laser entrance hole (LEH) during experiments. New time resolved measurements of the LEH are being incorporated into the analysis. This accounts for some of the apparent deficit in implosion velocity, but it raises additional questions about reconciling laser power with the inferred radiation drive on the capsule.
- Increased laser energy and power (1.6 MJ, 425 TW to date) and tuned the laser timing and energy deposition control.
- Increased efficiency in laser operations, including shot rate and preparation time between shots. Increased optics refurbishment rate to an impressive 30 per week with a target of 40 per week in the near future.
- Improved target fabrication, characterization and assembly with extension to beryllium (Be) and high-density carbon (HDC ~ diamond) capsules and depleted uranium hohlraums. Cryogenic target production increased roughly from 10/mo in June to 20/mo in December.

Gaps in Understanding

The gaps in understanding identified in the 4th Koonin report remain and are increasingly associated with fusion yield that is lower than expected by a factor of 10. Both laser-hohlraum coupling for radiation drive and ablator behavior during compression have unexpected features.

- **Symmetry**: The NIC team feels that they have adequate control of the radiation drive in the hohlraum to control the shape of implosions. However, the control of energy deposition by the laser beams in the hohlraum, achieved through tuning experience, remains uncertain for cases for which the laser drive is changed from tested values. For example, a deliberate test of a decrease in the spot size of one inner (23 degree) laser beam increased the backscatter of laser light due to stimulated Brillouin scattering (SBS) by a factor of 5. This result is a consequence of laser-plasma interactions. Because of such effects, changes in applied laser power sometimes result in an implosion shape different from expected. In the long term, improvements in understanding of laser-hohlraum interaction would be beneficial.
- **Ablator behavior**: The NIC team has been augmented by other scientists in the program to address gaps in understanding of ablator performance (pressure, density, and velocity). Jim Hammer and Howard Scott presented their application of improved non-local thermodynamic equilibrium (NLTE) models to the ablator issues, which explain, in part, the low velocity and the increased thickness of the ablator in-flight. This modeling, together with the correction for LEH size, can account for most of the observed behavior in velocity deficit and ablator broadening. However, this has not been confirmed with any focused experimental data, and these changes have not yet been incorporated into the configuration-controlled baseline implosion model. Additionally, these NLTE models predict the formation of a double ablation front leading to additional shocks and increased ablator entropy and, therefore, an increase in the ablator width and a decrease in density. While the expected improvement in agreement between experiments and

simulation with the improved NLTE physics will not change the measured yield, it is expected that this will improve the ability to design better performing ignition experiments. These models suggest, for example, that increasing the amount of silicon dopant in the ablator shell will reduce the differences caused by NLTE effects, and it is anticipated that such doping changes will be tested. Additionally, because of differences in the atomic properties of plastic (CH) and beryllium (Be), NLTE effects should have less impact on the performance of Be capsules. Therefore, there is some increased impetus to consider Be capsules, even though use of Be may slow the experimental rate due to procedural controls.

- **Mix:** Understanding hydrodynamic mixing of ablator material, cold DT layer, and the DT hot spot is important for ignition and is related to other high energy density experiments. At higher implosion velocities the ablator shell may be sufficiently unstable that its breakup introduces ablator material or cold DT into the hot compressed DT core. Irregularities in the ablator surface, the DT ice surface, or any of the material interfaces provide seeds for instability growth. Mix phenomena have been studied for years, but the NIC reaches new regimes. A well-designed program of deliberate variations in these factors will improve knowledge of the constraints to be met in target preparation. The near-term plan presented by Bruce Remington could elucidate these issues.

Summary and Expectations

It remains true that achieving self-sustained thermonuclear fusion in the laboratory is a difficult technical undertaking. The NIC team and the laser are performing well, and improvements in fusion output should be achieved. However, the path toward achieving a sustained level of increased performance is not yet clear, and success in the form of ignition within the NIC schedule is not assured. As identified in the 4th Koonin report, an important measure of progress will be the attempt to obtain improved fusion yield and associated alpha deposition heating of the compressed fuel that is now to be attempted by May.

Whereas significant progress has been made in advancing the individual parameters believed to be required for ignition, these parameters are neither independent nor do they scale linearly. It is difficult to report on quantitative progress towards integrated ignition performance since no cryogenic layered implosions have been performed that integrate these improvements at a consistent total drive energy (e.g. 1.6 MJ). Integrated experiments already reveal dependencies that require further adjustment through additional tuning experiments. High priority should be given to the implementation of improved physics models in the baseline design codes. High priority also should be given to application of experimental improvements (uranium hohlraums and higher laser power with selected power controls) in integrated performance tests. It is important to execute these changes in a disciplined manner (as has been the case), but the priority needs are clear.

In response to the recognized need to develop planning beyond the end of NIC, a NNSA/laboratory ICF management meeting was held in January. In that meeting, it was agreed that working groups would be formed to develop plans, scientific priorities, and schedules for ICF facilities in support of the Stockpile Stewardship Program. The products of these working groups will be reviewed at a subsequent ICF management meeting scheduled for June.